USDA United States Department of Agriculture | Forest Service | Northeastern Area State and Private Forestry | 180 Canfield Street Morgantown, WV 26505-3101

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John Donahue
Superintendent
USDI National Park Service
Delaware Water Gap National Recreation Area
Headquarters, River Road
Bushkill PA 18324

Dear Mr. Donahue:

Enclosed is the biological evaluation covering the hemlock woolly adelgid (HWA) and elongate hemlock scale (EHS) at the Delaware Water Gap National Recreational Area. A total of ten areas were evaluated in January 2007 including: Childs Park, Dingmans Falls, Hackers Falls, Upper and Lower Hornbecks Creek, PEEC Spanckman's Ravine, and Raymondskill Falls areas on the Pennsylvania side and Buttermilk Falls, Copper Mine Trail, and Van Campens Glen Picnic Area on the New Jersey side of the park.

In brief, HWA is present at all the surveyed areas. Populations are variable, and range from low to moderate densities. EHS populations are at very low levels at most of the survey sites, with the exception of a few trees with moderate EHS scale populations at Van Campens Glen Picnic Area and Upper and Lower Hornbecks Creek.

Based on this evaluation and your management objectives as we understand them, we continue to recommend chemical treatment of hemlock trees in high profile areas where possible. In other hemlock stands within the park, we encourage the continued release of HWA natural enemies, as they become available.

Brad Onken of this office continues to work with your resource management staff to implement these and other related management actions and if you have any questions, please don't hesitate to contact him at (304) 285-1546.

Sincerely,

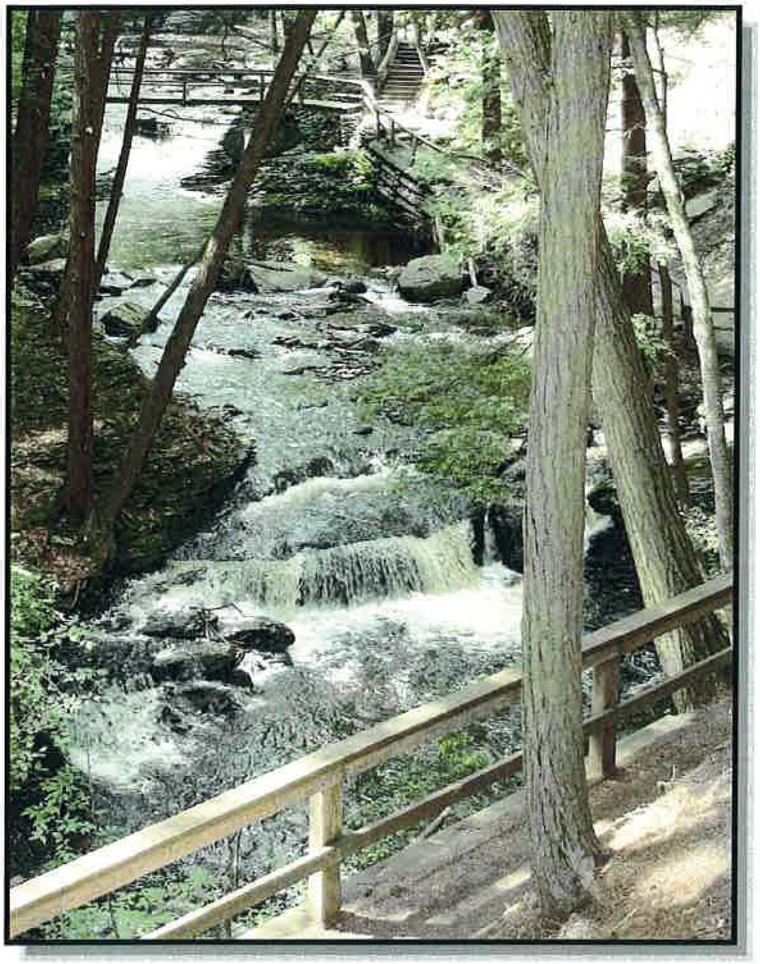
Bob Lueckel

ROBERT G. LUECKEL
Field Representative MFO

Enclosure

Cc: Richard Evans, DWGNRA
Wayne Millington, USDI NPS
Noel Schneeberger, AO

Biological Evaluation of
Hemlock Woolly Adclgid and Elongate Hemlock Scale
At
Delaware Water Gap National Recreation Area,
Milford, Pennsylvania
June, 2007



Prepared by

Karen Felton, Biologist
And
Bradley Onken, Entomologist
USDA Forest Service
State and Private Forestry
Forest Health Protection
180 Canfield Street
Morgantown, WV 26505

ABSTRACT

On January 29-31, 2007 personnel from the USDA Forest Service, Northeastern Area, Forest Health Protection, Morgantown Field Office, and USDI National Park Service, Delaware Water Gap National Recreation Area conducted a survey to evaluate hemlock woolly adelgid (HWA), *Adelges tsugae*, and elongate hemlock scale (EHS), *Fiorinia externa*, population densities at Delaware Water Gap National Recreation Area (DWGNRA) in northeastern Pennsylvania and northwestern New Jersey. The purpose of the survey was to assess the need for treatment in the Childs Park, Dingmans Falls, Hackers Falls, Upper and Lower Hornbecks Creek, PEEC Spanckman's Ravine, and Raymondskill Falls areas on the Pennsylvania side and Buttermilk Falls, Copper Mine Trail, and Van Campens Glen Picnic Area on the New Jersey side of the Park. Elongate hemlock scale is basically present throughout the survey areas but at very low levels. HWA is also present throughout the survey area, and control of HWA on accessible, individual, high-valued, infested hemlock trees at DWGNRA is recommended to prevent further decline of tree health. The release of predatory beetles, when available, is also recommended as a biological control strategy and future control of HWA.

INTRODUCTION

HEMLOCK WOOLLY ADELGID

Adelgids are small, soft-bodied insects that feed exclusively on conifers. The family is divided into two genera: *Adelges* and *Pineus.* There are six species of *Adelges* that occur in North America, of which only one is native (Montgomery 1999), the Cooley spruce gall aphid (*Adelges cooleyi*). This adelgid occurs coast to coast in northern North America. Its primary hosts are recorded as white (*Picea glauca*), blue (*Picea pungens*), Sitka (*Picea sitchensis*), and Engelmann (*Picea engelmannii*) spruce (Baker 1972). It has an alternate host, Douglas fir (*Pseudotsuga menziesii*). There are 10 species of *Pineus* that occur in North America, of which seven are native. Four of these the pine bark adelgid (*Pineus strobi*); the pine leaf adelgid (*P. pinifoliae)*; the red spruce adelgid (*P. floccus*); and the spruce gall adelgid (*P. similes*) seem to be indigenous to eastern North America (Drooz 1989, Montgomery 1999). These species attack eastern white pine (*Pinus strobus*), red spruce (*Picea rubens*), and black spruce (*Picea mariana*) but seldom cause extensive damage (Drooz 1989, Montgomery 1999). Little is known about the population dynamics, ecological role, or the predator complex associated with these native adelgids.

Native to Japan, the hemlock woolly adelgid (*Adelges tsugae)* is a pest of eastern hemlock (*Tsuga canadensis*) and Carolina hemlock (*T. caroliana*) (Onken et al. 1999), both of which are considered highly susceptible to the adelgid, with no documented resistance (Bentz et al. 2002). The latter tree species is found only in the southern region of the Appalachian Mountains (Onken et al. 1999). The HWA is currently established in

17 eastern states from Georgia to Maine, and tree decline and mortality have increased at an accelerated rate since the late 1980s. For example, in the Shenandoah National Park (SNP), hemlock crown health has declined since the early 1990s. In 1990, greater than 77 percent of the hemlocks sampled were in a "healthy" condition; by 1998, less than 10 percent were in a "healthy" condition (Akerson and Hunt 1998). In another study at SNP, tree mortality significantly increased from an initial 8 percent in 1990 to nearly 50 percent in 2000 (Bair 2002). In New Jersey twelve years after initial HWA infestations, tree mortality reached more than 90% in some hemlock stands (Mayer et al 2002).

The hemlock woolly adelgid is parthenogenetic (an all-female population with asexual reproduction) that has six stages of development: the egg, four nymphal instars, and the adult, and two generations a year on hemlock. The winter generation, the sistens, develops from early summer to midspring of the following year (June-March). The spring generation, the progrediens, develops from spring to early summer (March-June). The generations overlap in mid to late spring.

The hemlock woolly adelgid is unusual in that it enters a period of dormancy during the hot summer months. Prior to dormancy, the nymphs produce a tiny halo of wool-like wax filaments surrounding their bodies. The adelgids begin to feed once cooler temperatures prevail, usually in October and continue throughout the winter months. As it matures this woolly covering increases in size and becomes more conspicuous. This woolly sac (ovisac) helps protect the insect and its eggs from natural enemies and prevents them from drying out. These ovisacs can be readily observed from late fall to early summer on the underside of the outermost branch tips of hemlock trees.

Figure 1. Hemlock woolly adelgid nymphs in dormancy.

Figure 2. Hemlock woolly adelgid ovisacs (woolly sac).

The ovisacs of the winter generation contain up to 300 eggs, while the spring generation ovisacs contain between 20 and 75 eggs. The hemlock woolly adelgid also has a winged form that is produced by the spring generation. This form must complete part of its life cycle on spruce. The apparent lack of a suitable spruce host for this form in eastern North America results in a substantial loss of adelgids each year (McClure 1992b). Although natural mortality in HWA populations is commonly between 30 to 60 percent

(McClure 1989, 1996), the reproduction potential of this insect remains high. Other mortality is generally attributed to two likely causes: 1) an extended period of cold temperatures or rapid temperature changes that coincides with a susceptible period of development for the adelgid, and/or 2) a sufficient loss in the nutritional quality and quantity of the food source, which is associated with the decline in health and vigor of the host tree (McClure 1996, Onken et al. 1999).

Adelgid feeding can kill a mature tree in about 5 to 7 years (McClure et al. 2001). This tiny insect (~ 1 mm) feeds on all life stages of hemlock, from seedling to mature, old growth tree. The first instar nymphs, called crawlers, search for suitable sites at the base of the hemlock needles, and insert their feeding stylets into the young hemlock twigs and are committed to that feeding site throughout the remainder of its development. The stylet bundle is more than three times the length of the insect and penetrates deep within the plant tissues. HWA does not deplete nutrients directly by feeding on the sap, but rather by depleting the food reserves from the tree's storage cells (McClure et al. 2001).

Dispersal and movement of HWA during its egg and mobile first instar stages is associated with wind, birds, deer, and other forest dwelling mammals. Humans also move the adelgid during logging and recreational activities and movement of infested nursery stock (McClure 1995). Natural enemies capable of maintaining low-level HWA populations are nonexistent in eastern North America (Van Driesche et al. 1996, Wallace and Hain 1998).

HWA was first reported in the western U.S. in the 1920s (Annand 1924, McClure 2001). HWA populations on western tree species, including western hemlock (*Tsuga heterophylla*) and mountain hemlock (*T. mertensiana*), appear to be innocuous; these tree species are believed to be resistant because little damage has been reported (McClure 2001). Unfortunately, both these trees are of limited value for hybridization and planting due to their poor adaptation to the east coast environment (Bentz et al. 2002). In the East, HWA was first reported in 1951 near Richmond, Virginia. It was considered to be more of an urban landscape pest and was controlled using a variety of insecticides applied with ground spraying equipment. Observations of the adelgid were periodically reported in several Mid-Atlantic States in the 1960s and 1970s but it was not until the 1980s that HWA populations began to surge and spread northward to New England at an alarming rate. By the late 1980s to early 1990s, infestations of HWA were reported to be causing extensive hemlock decline and tree mortality in hemlock forests throughout the East (McClure 2001).

SCALE INSECTS

There are several scale insects that affect hemlocks in the eastern United States. The more common ones belong to the family *Diaspididae*, or armored scales. Armored scales form a protective cover that is unattached to the body. The hemlock scale, *Abgrallaspis ithacae,* is native to the United States and is probably present throughout the East. *A. ithacae* is generally not a significant pest (Johnson and Lyon 1988). The hemlock scale has also been reported on fir (*Abies* species) and spruce (*Picea* species) (Drooz 1989).

Two exotic scales that attack the eastern and Carolina hemlock are the elongate hemlock scale, *Fiorinia externa*, and the shortneedle evergreen scale (a circular hemlock scale), *Nuculaspis tsugae* (Johnson and Lyon 1988, McClure 2002a). Native to Japan, the shortneedle evergreen scale and the elongate hemlock scale were first reported in the United States, in 1910 and 1908, respectively. The shortneedle evergreen scale is now known to occur in Connecticut, Maryland, New Jersey, Rhode Island, and New York (McClure 2002a), and its hosts other than hemlock include fir, cedar (*Cedrus* species), spruce and yew (*Taxus* species) (Drooz 1989). The EHS has been found in the District of Columbia and in nine states from Virginia to southern New England and west to Ohio (McClure 2002b). The EHS is known to occur on species of spruce, fir, yew and hemlock (Drooz 1989). Spruce and fir tend to be even more susceptible than hemlock, although it has not yet spread into the natural ranges of these other native conifers. Circular hemlock scale is far less abundant and generally out competed by the elongate hemlock scale (McClure 2002a).

The EHS completes two generations each year in the southern and mid-Atlantic states, but usually only one in the Northeast. Its life stages are broadly overlapping everywhere, and crawlers can be found throughout the spring and summer. Crawlers are the only stage capable of dispersing and establishing new infestations. Dispersal between trees is primarily by wind and birds. Females have three stages of development after the egg stage, while males have five. During the first and second instar stages, both sexes settle beneath the thin waxy cuticle on the lower surface of the youngest hemlock needles and begin to feed. While in these stages, both sexes secrete a cover around itself as it grows. Adult female covers are elongate and translucent light yellow to brown in color, and approximately 2mm long. The male cover is elongate, white and about 1.5mm long. After the first and second nymphal instar stages, the female then molts into the adult feeding stage, while the male molts into a non-feeding prepupa and spins a cocoon, where it pupates before it emerges as an adult. The adult male mates with the female and dies soon thereafter without feeding. The adult female lays about 20 eggs within her cover. The EHS usually overwinters, either as an egg or as an inseminated adult female. When the crawlers hatch, they exit through a small opening at the posterior end of the cover (McClure 2002b).


Figure 3. Elongate hemlock scale on the lower surface of hemlock needles.

The EHS attacks the underside of the hemlock needles by removing fluids from the mesophyll cells through piercing and sucking mouthparts. Scale populations build slowly on healthy trees, but much more quickly on stressed ones. Feeding by HWA has been shown to affect nutrient dynamics in hemlock stands (Jenkins et al. 1999) and this could feasibly reduce tree vigor sufficiently to allow scale insects such as EHS to become established and explode in population size (Danoff-Burg and Bird 2002). Mixed infestations of EHS and HWA can greatly hasten hemlock decline. Feeding by EHS causes foliage to turn yellow and drop

prematurely. Dieback of major limbs, which usually progresses from the bottom of the tree upwards, usually occurs after scale density reaches about 10 individuals per needle. Trees often die within the next 10 years, but some survive longer in a severely weakened condition with only a sparse amount of foliage at the very top of the crown. These weakened trees have very little chance of recovery and often fall victim to secondary pests, such as hemlock borer and *Armillaria* root disease or readily broken and thrown by wind (McClure 2002b).

HEMLOCK IMPORTANCE

Eastern hemlock is an extremely shade tolerant tree species, capable of surviving for as long as 350 years underneath a shaded forest canopy (Quimby, 1996). It is a slow-growing long-lived tree. It may take 250-300 years to reach maturity and may live for 800 years or more (Godman and Lancaster 1990). Eastern hemlock forests create distinctive microclimates and provide important habitat for a variety of wildlife, such as birds, fish, invertebrates, amphibians, reptiles and mammals. In the Northeast, 96 bird and 47 mammal species are associated with hemlock forests at some point during their life (Yamasaki et al. 2000).

Hemlock trees contribute to the ecological, aesthetic and recreational values of Delaware Water Gap NRA. Eastern hemlock is an important component of the forest, covering approximately 2, 800 acres (about 5%) of DWGNRA (Myers and Irish 1981, Young et al. 1998). Many scenic waterfalls are associated with hemlock stands at DWGNRA. Popular recreational activities in these areas of the recreation area include hiking, trout fishing, bird watching, sight seeing, and picnicking.

Some of the more heavily used hemlock forests at DWGNRA include the following areas:

Dingmans Creek (trails and visitor center)
Adams Creek (state designated "exceptional value" trout streams)
Toms Creek (state designated "exceptional value" trout streams)
Raymondskill Creek (trails)
Hornbecks Creek (important to the Pocono Environmental Education Center)
Tumbling Waters (important to the Pocono Environmental Education Center)
Van Campens Brook (a "blue-ribbon "trout stream and picnic area)
Buttermilk Falls
Copper Mine ravine
Dunnfield Creek
Childs Park

A number of research projects have been and are currently being conducted in the park to focus on aspects of HWA and hemlock forest ecology and biodiversity. Topics include the effects of HWA and hemlock decline on understory vegetation, birds, hemlock tree growth and foliage chemistry, and nutrient (especially carbon and nitrogen) dynamics in forest vegetation, soils, and streams.

Recent studies conducted in DWGNRA have documented many distinctive characteristics of hemlock forests and ecosystems (Evans 2000). At Adams Creek and VanCampens Brook, 316 species of plants have been documented (Battles et al. 2000). Hemlock ravines in DWGNRA support more than 15 species of amphibians and more than 12 species of small mammals; relatively high numbers when compared to many other forest types in the region (Sciascia and Pehek 1995). At least 152 species of ground invertebrates occur in hemlock forests at the recreation area (Schweitzer 1994).

An avian study conducted in DWGNRA has shown that the Acadian flycatcher (*Empidonax virescens*), blue-headed vireo (*Vireo solitarius*), black-throated green warbler (*Dendroica virens*), and Blackburnian warbler (*Dendroica fusca*), showed a high affinity for hemlock forest type and exhibited significantly greater numbers of territories in hemlock than hardwood sites. The blue-headed vireo, a low-to-mid canopy species, and the Blackburnian warbler, a mid-to-upper canopy forager, appear to specialize on ravine meso-habitats of hemlock stands (Ross et al. 2004).

Figure 4. Bird nest in hemlock tree at Childs Park, March 2006.

Small streams in hemlock forests are three times more likely to support native brook trout populations than similar streams in hardwood forests in the Delaware Water Gap NRA (Snyder et al. 1998). Hemlocks create a cooling effect in summer that is a critical factor in supporting trout populations. Studies have shown that removal of hemlock trees within 80 feet of a stream can cause temperatures to rise 6 to 9 degrees Celsius (Lapin 1994). Hemlock forest streams typically support about 65 species of aquatic insects, compared to about 35 species in hardwood forest streams. There are about 15 species of aquatic insects that seem to occur almost exclusively in hemlock forest streams in the DWGNRA (Snyder et al. 1998).

HISTORY OF HWA AND OTHER FACTORS IMPACTING HEMLOCK HEALTH

HWA was first noticed within the DWGNRA in 1989 at Dunnfield Creek (New Jersey) and Mount Minsi (Pennsylvania) (Millington 1989). Since 1989, HWA has spread throughout the recreation area (Evans 2002). Donkey's Corner ravine was heavily infested with HWA by 1992. In 1995, HWA was detected at 30 of 58 (52%) surveyed sites located throughout DWGNRA. By 1999, HWA was found at all (100%) of the same 58 surveyed sites. In 1999, more than 50 percent of the hemlock trees evaluated at Mount Minsi, and three-quarters of the hemlock trees at Dunnfield Creek and Donkeys Corners were either dead or in decline (Evans 2000).

Other hemlock stressors have included the hemlock borer (*Melanophila fulvoguttata*), elongate hemlock scale, and periods of moderate drought in 1993, 1995, and 1998-2002 (NCDC 2006). In 1999-2001, hundreds of hemlock borer attacked trees were observed in the Raymondskill Creek, Conashaugh Creek, Dry Brook, Adams Creek, Dingmans Creek, Hornbecks Creek, and Spackmans Creek areas. The borer is typically a hemlock secondary pest and populations tend to build in hemlocks that have been stressed from other causes. Hemlock borer can become so abundant during these outbreaks that they attack otherwise healthy hemlock trees. DWGNRA experienced such an outbreak in 1999-2000, but fortunately populations began to subside by 2001. Increasing populations of elongate hemlock scale at DWGNRA was first observed in 2002. Prior to this, EHS populations had been at innocuous levels and often very difficult to find. EHS populations declined in 2005 which was likely the result of cold winter temperatures. However, the residual scale densities can be found throughout the Park and given the appropriate conditions can rebuild rapidly.

Figure 5. Damage caused by woodpeckers searching for hemlock borer.

IMPACTS TO HEMLOCK RESOURCES

In 1993, DWGNRA staff established individually marked hemlock trees in 81 permanent plots distributed among seven sites around the recreation area to assess hemlock tree health and monitor the impacts of HWA. From 1993 to 2002, crown transparency (relative amount of light that can pass through the tree crown) increased from 15 % to 35%. Crown dieback increased from about 5 % to over 20%. Vigor rating data collected in 2002 indicate that 25 % of the hemlock trees in the monitoring plots were either dead or in severe decline, 48% were in light to moderate decline, and 27% were healthy. As of 2006, estimates of hemlock conditions within the DWGNRA indicate that 27% of the hemlocks are dead and 69% are in either moderate or severe decline.

Figure 6. Cut trees at Childs Park, June 2004.

In 2002, about 250 dead or dying hemlock trees were cut down in Childs Park because of the potential hazard to vehicles, structures, and the health and safety of people (Evans 2002). Trees were cut down, tops were mulched and the boles were left on the ground to minimize erosion caused by heavy equipment and the steepness of the terrain.

More recently, the parking lots, trails and grounds surrounding Raymondskill Falls were closed from mid-July until October, 2005 due to hazardous conditions created by dead and dying trees. A total of 88 hazardous trees were cut down, of which 72 were hemlock trees (82%). The median

diameter breast height of the cut trees was 16 inches. Like Childs Park, downed trees were left on site (tops mulched, boles left on ground).

Figure 7. Cut trees at Raymondskill Falls, March 2006.

In a vegetation dynamics study conducted in two hemlock ravines at DWGNRA, Eschtruth et al. (2006) found that the average transmitted radiation more than doubled from 5.0% in 1994 to 11.7% in 2003 and the ground cover of vascular plants increased from 3.1% to 11.3 % in the same time frame. Species richness increased significantly during this study period but mainly as the result of invasive and exotic species. In 1994, no exotic invasive species were present in the vegetation plots and by 2003, exotic invasive plants were found in 35% of the vegetation plots. This study documents the dramatic changes in understory light availability, vegetation patterns, and the potential management concern for invasive and exotic plants due to declining hemlock stands at DWGNRA.

Figure 8. Abundant fern growth at Adams Creek, August 2005.

Exotic invasive plant species currently found within the park and invading declining hemlock stands include: Japanese barberry (*Berberis thunbergii*), Japanese stiltgrass (*Microstegium vimineum*), tree-of-heaven (*Ailanthus altissima*), garlic mustard (*Alliaria petiolata*), and multiflora rose (*Rosa multiflora*) (Evans 2003).

HISTORY OF HWA, EHS, AND HEMLOCK MANAGEMENT ACTIVITES

Biological Control: From 2000 to 2004, DWGNRA has released 75,700 *Sasajiscymnus tsugae* predatory beetles for HWA biological control in fourteen areas within the park (11 in NJ, 3 in PA). At the Camp Ken-Etiwa-Pec release site in NJ a single *S. tsugae* beetle was recovered 3 years after the release date.

In 2006, 1,000 *Scymnus sinuanodulus* predatory beetles were release near the southeast side of Hemlock Pond in NJ, and 300 *Laricobius nigrinus* predatory beetles were release along the border of the "hogback" and adjacent wetland in PA.

In 2006, a total of 10,000 EHS predatory beetles, *Cybocephalus nipponicus*, were released at five areas in the park.

Chemical Control:

In 2006, hemlock stands at Childs Park, Dingmans Falls, Raymondskill Falls, Buttermilk Falls and VanCampens Picnic Area were selected for chemical suppression of HWA.

A total of 336 trees were treated with the soil injection method using the Kioritz soil injector with Merit 75WSP and 132 trees were treated by stem injections using the Arborjet "Tree IV" system using Imajet insecticide (Tables 1 and 2).

Figure 9. Soil injections being performed with the Kioritz soil injectors and Merit 75WSP, April 2006.

Table 1. Soil injection summary using Merit 75WSP.

Site	Treatment Area (acres)	No. Trees Treated	Ave. Tree Diameter (in.)	Total grams of Imidacloprid	When Treated (Spring/Fall)
Childs Park (pilot study)	2	12	23	197	S
Dingmans Falls	12	111	21	2,223	S
Raymondskill Falls	5	65	15	923	S
Buttermilk Falls (NJ)	2	30	16	462	S
VanCampens Picnic	1	11	19	201	S
Childs Park	12	107	20	1,869	F

Table 2. Stem injection summary using IMA-jet.

Site	Treatment Area (acres)	No. Trees Treated	Ave. Tree Diameter (in.)	Total grams of Imidacloprid	When Treated (Spring/Fall)
Dingmans Falls	12	44	21	576	S
Raymondskill Falls	5	13	14	66	S
Childs Park	12	75	19	667	F

Hemlock Stand Management:

Figure 10. Garlic mustard at Raymondskill Falls, April 2006.

A Forest Restoration Project funded by the Northeast Regional Science Program was initiated at Raymondskill Falls in 2006. In conjunction with support provided by the USDA Forest Service Northeastern Area the goal is to protect the remaining hemlocks, prevent invasion of alien plants, foster hemlock regeneration and other desired tree species, minimize erosion, and inform and educate the public. The Park's Exotic Plant Management Team started the process of eliminating the exotic species from this area, and will be continuing the effort in the future. The Park's Research and Resource Planning Division staff planted 35 white pine, 17 Eastern red cedars and 2 sugar maples saplings in an effort to foster native tree regeneration. A 7-8 foot high woven wire fence was installed around 2.3 acres to protect existing seedlings and saplings from deer browsing. New interpretive signs were installed to explain the restoration project to visitors.

METHODS

The hemlock woolly adelgid sampling plan was used to evaluate HWA populations in hemlock stands by assessing the percentage of infested trees (Costa and Onken, 2006). This sampling plan measures the infestation level of the stand rather than individual trees and does not involve laborious counting of HWA. By rapid examination of branches on 8 to 100 trees, HWA infestations can be characterized and as few as 2 percent of infested trees can be detected with 75 percent reliability. The cutoff thresholds to stop sampling are based on optimum sample sizes to obtain a relative precision level of 0.25. Other levels of detection and reliability can also be selected if desired (Table 3).

Table 3. Maximum number of trees that must be examined to detect an infested tree by minimum detection threshold (minimum percent of infested trees) and reliability level (probability of finding a single infested tree). The shaded area encompasses the recommended 100-tree sample. (Costa and Onken, 2006)

Minimum % Infested Trees in Stand	Reliability Level (%)			
	50	75	95	99
0.5	138	277	598	919
1	69	**138**	298	458
2	34	**69**	148	228
3	23	46	98	151
5	14	27	58	90
10	7	13	28	44
20	3	6	13	21

This sampling method is best suited for stands 10 acres or larger, but smaller stands can be examined.

Each stand surveyed was roughly divided into four blocks (Figure 11). The first tree was arbitrarily selected in the first block of the stand. Selected trees had two branches that could be reached, if possible, but a second branch on an adjacent or nearby tree was acceptable. A branch was selected and closely examined for the presence or absence of white woolly masses (old or new) within the terminal meter of the foliage. If HWA was found on the first branch, it was recorded and the second branch was not surveyed. If no woolly masses were observed on the first branch, then a second branch was selected and surveyed. The data recorded is a running tally (sum) of the number of trees positive for HWA presence.

The next tree was determined by randomly selecting a direction that would provide coverage in that block and pacing out approximately 25 paces (2 steps per pace) to another hemlock tree, and the survey process was repeated. In the first block, up to 25 trees would be surveyed if the stop threshold was not reached. The survey would begin again in block two, and again up to 25 trees (50 trees total) surveyed, and if the threshold was not reached, then this process was repeated in blocks 3 (75 trees total) and 4 (100 trees total). When the tally count reached the corresponding threshold, then the survey stopped, or when 100 trees were sampled, which ever came first.

In addition to the stand level assessment, qualitative information regarding HWA and EHA densities on individual trees was also collected. On each branch, HWA infestation

densities were designated by visually inspecting each branch sample as heavy, moderate, light or none basсd on an cstimated percentage of tips with adelgid present and categorized as follows:

Heavy (H) = >50% infested
Moderate (M) = 50% to 25% infested
Light (L) = <25% infested
None (N) = 0% infested

EHS density estimates were also designated by visually inspecting each branch sampled as heavy, moderate, light or none based on the criteria below:

Heavy = >1/needle on average
Moderate = 1/needle on average
Light = <1/needle on average
None = 0% infested

A GPS (global positioning system) unit was used to collect coordinates (decimal degrees, WGS84) and map the area surveyed within the Park. A GPS point represented the general area of each stand.

Figure 11. Example of the hemlock woolly adelgid sampling plan data sheet used at Delaware Water Gap National Recreation Area, 2007.

Site/Location:		**HWA density**	**Scale density**
GPS Locations: B1		**N, L**<25%	**N, L**<1 scale/needle
B2 **B3** **B4**		**M**=25-50%	**M**=1 scale/needle avg
Date:		**H**>50%	**H**=multiple scale/needle
Surveyor(s):		**Comments:**	

Path Direction	Tree	Sum HWA Trees	STOP > Threshold	Visual Estimate HWA	SCALE	Path Direction	Tree	Sum HWA Trees	STOP > Threshold	Visual Estimate HWA	SCALE
Block 1	1		n/a			Block 3	51		12		
NE	2		n/a			NE	52		12		
SE	3		n/a			E	53		12		
N	4		n/a			S	54		12		
NW	5		n/a			SE	55		12		
SW	6		n/a			SE	56		12		
S	7		n/a			S	57		13		
S	8		8			W	58		13		
SE	9		8			NW	59		13		
SW	10		8			S	60		13		
W	11		8			NW	61		13		
S	12		8			NE	62		13		
E	13		8			W	63		13		
E	14		8			NW	64		13		
NE	15		8			N	65		13		
SE	16		8			NE	66		13		
NE	17		8			NE	67		13		
E	18		8			W	68		13		
N	19		9			N	69		13		
NW	20		9			N	70		13		
N	21		9			E	71		13		
W	22		9			SE	72		13		
S	23		9			NE	73		13		
W	24		10			SE	74		13		
W	25		10			SW	75		13		
Block 2	26		10			Block 4	76		13		
E	27		10			N	77		13		
SE	28		10			E	78		13		
NE	29		10			N	79		13		
SE	30		10			SE	80		13		
NE	31		11			SW	81		13		
E	32		11			S	82		13		
N	33		11			SW	83		13		
N	34		11			S	84		13		
SW	35		11			W	85		13		
W	36		11			N	86		13		
SW	37		11			W	87		13		
NW	38		11			W	88		13		
NW	39		11			NE	89		13		
NE	40		11			N	90		13		
N	41		12			N	91		14		
SW	42		12			NW	92		14		
W	43		12			N	93		14		
NW	44		12			SE	94		14		
SW	45		12			NE	95		14		
W	46		12			N	96		14		
SE	47		12			E	97		14		
S	48		12			SE	98		14		
E	49		12			E	99		14		
S	50		12			NE	100		14		

RESULTS

A total of ten areas were survey within DWGNRA: Buttermilk Falls, Van Campens Glen Picnic Area, Copper Mine Trail, Raymondskill Falls, Hackers Falls, Childs Park, Upper and Lower Hornbeck, PEEC-Spanckman's Ravine, and Dingman Falls. The survey areas are represented in Figures 12a-b, and a summary of the stand level data is presented in Table 4.

All survey areas reach a STOP threshold of eight trees within the first block of the stand, and the percentage of trees infested ranged from 61-100 percent. HWA densities within tree were observed to range from very light to moderate between the survey areas. Elongate hemlock scale was present at all survey sites but found at only low densities, with the exception of a few trees with moderate scale densities at Van Campens Glen Picnic Area and Upper and Lower Hornbecks Creek.

In general it was observed that hemlocks are in light-moderate decline within most of the survey areas. Hemlocks at Dingmans Falls and Lower Hornbecks Creek were in somewhat poor condition and have thinning crowns. The remaining live hemlock trees at Copper Mine Trail were in very poor health and mite damage on some trees was observed.

Table 4. Summary of HWA and EHS survey data collected in Winter, 2007 at DWGNRA.

Location	# Trees Surveyed	STOP Threshold (# HWA positive trees)	Visual Estimate	
			HWA Range[1]	EHS Scale Range[2]
Raymondskill Falls	8	8	L	L
Hackers Falls	13	8	N-L	N-L
Dingmans Falls	8	8	L-M	L
Childs Park	8	8	L	N-L
Upper Hornbeck	8	8	L	N-M
Lower Hornbeck	8	8	L	L-M
PEEC- Spanckman's Ravine	10	8	N-L	N-L
Buttermilk Falls	8	8	L	N-L
Van Campens Glen Picnic Area	8	8	L	L-M
Copper Mine Trail	8	8	L-M	N-L

[1]HWA infestation densities were designated by visually inspecting each branch sample based on an estimated percentage of tips with adelgid present and categorized as follows:

Heavy (H) = >50% infested
Moderate (M) = 50% to 25% infested
Light (L) = <25% infested
None (N) = 0% infested

[2]EHS density estimates were also designated by visually inspecting each branch sample as heavy, moderate, light or none based on the criteria below:

Heavy = >1/needle on average
Moderate = 1/needle on average
Light = <1/needle on average
None = 0% infested

Figure 12a. Hemlock woolly adelgid and elongate scale survey locations at Delaware Water Gap NRA, Milford, PA – Hackers Creek, Raymondskill Falls, Childs Park, and Dingmans Falls areas on the Pennsylvania side of the Park – Winter, 2007.

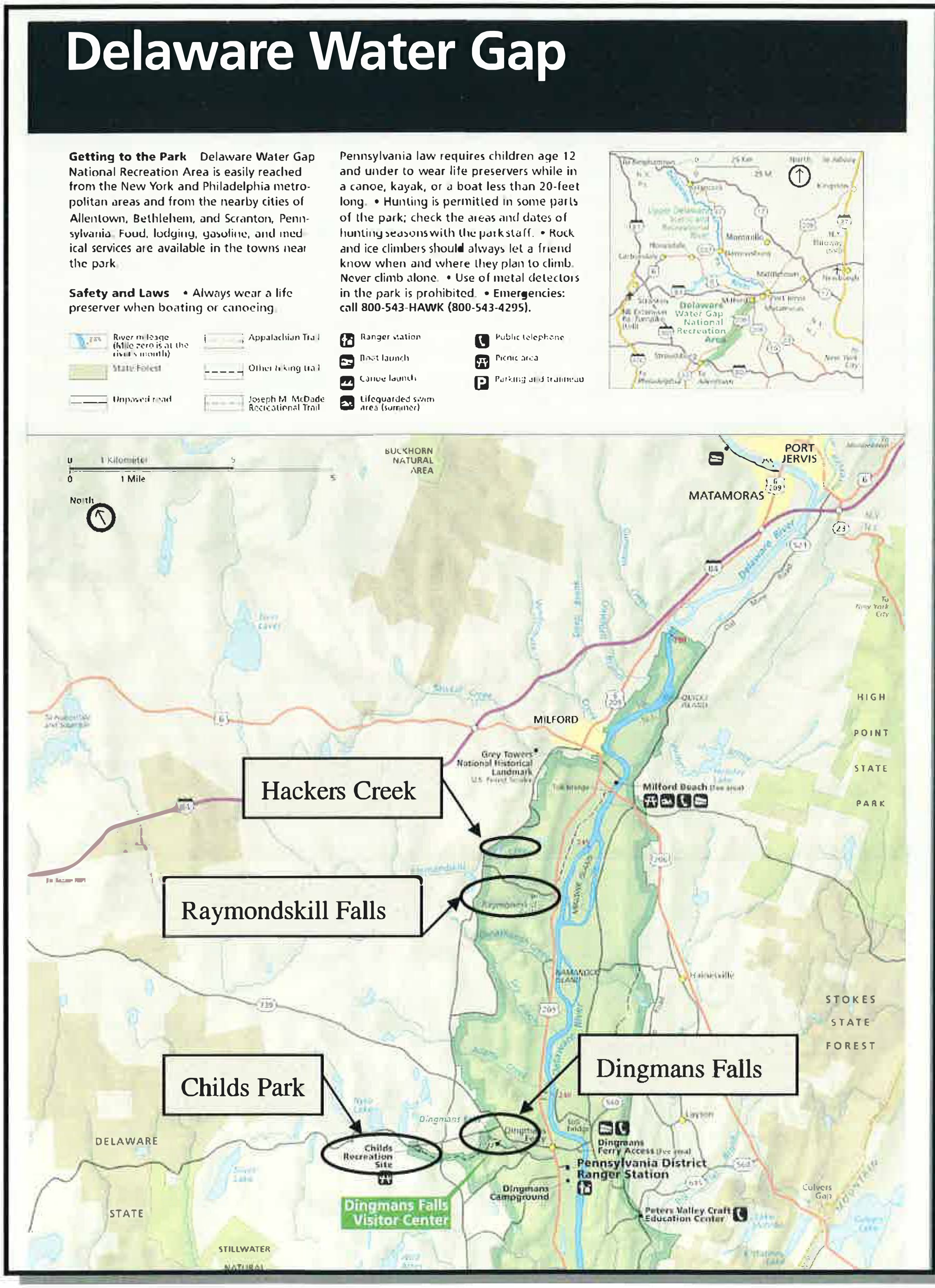
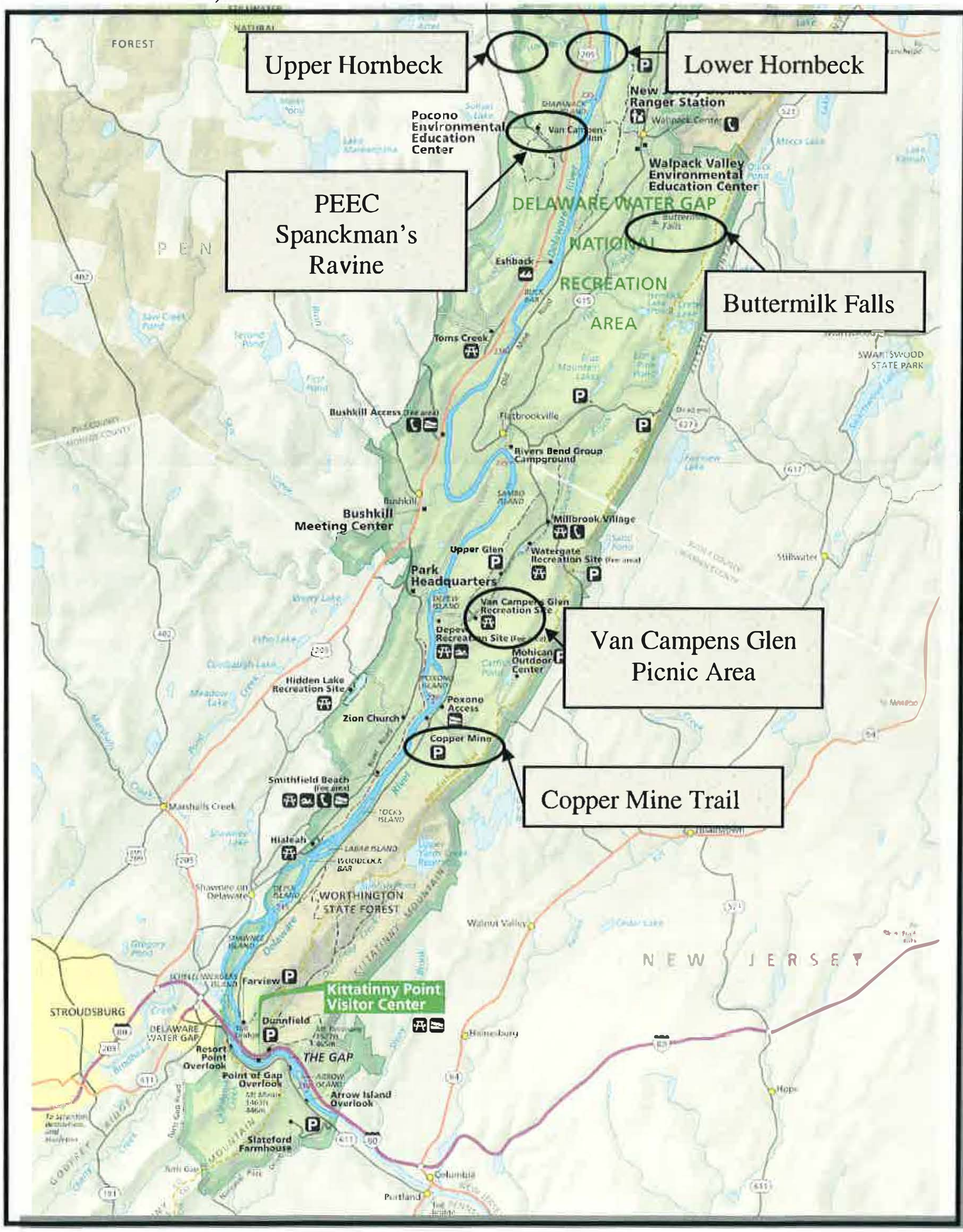


Figure 12b. Hemlock woolly adelgid and elongate scale survey locations at Delaware Water Gap NRA, Milford, PA – Upper and Lower Hornbecks Creek and PEEC Spanckman's Ravine areas on the PA side of the Park and Buttermilk Falls, Van Campens Glen Picnic Area, and Copper Mine Trail on the New Jersey side of the Park – Winter, 2007.



DISCUSSION

HWA populations are generally low throughout most of the survey areas. HWA densities are highly variable between trees, ranging from none to moderate, and all sites have an established population. Consequently, impacts to hemlock resources throughout DWGNRA will continue to increase if a second surge of HWA populations occurs. This pattern of distribution is conducive to outbreak populations when conditions are favorable.

Predicting year to year changes in HWA densities is difficult because of the dynamic nature of the many variables involved. Factors such as future climatic conditions, changing micro habitat (tree and site) conditions and other biotic and abiotic factors affect both survival and fecundity of HWA. Existing conditions at DWGNRA including the past two mild winters lead us to believe that adelgid populations could reach outbreak levels (again) in the near future.

Management Considerations

Chemical management options for protecting hemlock stands are limited by the biology and feeding behavior of HWA, pest population densities, site conditions (i.e. proximity to streams), accessibility and limited application technology currently available. Insecticide treatments although effective, are conducted on an individual tree basis which can be both labor intensive and costly. Thus treatment strategies are typically focused in high value sites such as recreational or scenic areas or where hemlock stands have an important ecological role or genetic preservation is a high priority. Classical biological controls such as predators and pathogens are being pursued by the USDA Forest Service but will likely take years to become effectively established. As such, preservation of hemlocks in the short term will require intensive monitoring and periodic chemical treatments when infestations are discovered.

Foliar chemical treatments. Aerial spray using horticultural oil or insecticidal soap is not an option because aerial sprays could not provide the needed "saturation" necessary to ensure that the insecticide adequately covers the insect. Aerial spraying with more toxic insecticides (e.g. malathion or diazinon) would have very significant, unacceptable impacts on a wide range of non-target insects and other animals and limited control benefits (Evans 2000). Application of insecticides using ground spraying equipment is generally limited to areas accessible to hydraulic spray equipment and areas where over spray or run off would not contaminate streams, lakes or ponds. Backpack sprayers could be effectively used for foliar treatment of infested seedlings and saplings to protect regeneration.

Systemic Insecticides. Several systemic insecticides are labeled for adelgids and can be injected (e.g. imidacloprid, bidrin or Metasystox-R®) or implanted (e.g. acephate) into hemlock trees. imidacloprid is by far the most common systemic insecticide being used to control HWA and is applied as a soil drench or injected into to the soil around hemlock trees. These insecticides are absorbed and trans-located by the vascular system of the tree

to feeding adelgids and will effectively suppress HWA populations (Doccola et al. 2003, Webb et al. 2003, Evans 2000, Steward and Horner 1994, McClure 1992a). Soil injection in sandy or saturated soils should be avoided as leaching of imidacloprid into the soil profile and groundwater (McAvoy et al. 2002) is a possibility. Soil injections immediately adjacent to creeks or other open waters and areas prone to frequent flooding should be avoided. Imidacloprid formulated as a trunk injection is available under the trade names Pointer®, IMA-jet® and Imicide® and are labeled for tree injection for the control of adelgids. Both stem and soil treatments of imidacloprid have become the preferred treatment for HWA in high value hemlock stands by state and federal resource managers. A further discussion of this product follows.

Imidacloprid is a relatively new insecticide in the family of chemicals called neonicotinoids (Felsot 2001) in the chloronicotinyl subgroup (USDA Animal and Plant Health Inspection Service 2002). It has a mode of action similar to that of the botanical product nicotine, functioning as a fast-acting insect neurotoxicant (Schroeder and Flattum 1984) that binds to the nicotinergic receptor sites in the postsynaptic membrane of the insect nerve (USDA Animal and Plant Health Inspection Service 2002), mimicking the action of acetylcholine, and thereby heightening, then blocking, the firing of the postsynaptic receptors with increasing doses (Schroeder and Flattum 1984, Felsot 2001). Because imidacloprid is slowly degraded in the insect, it causes substantial disorder within the nervous system, leading in most cases to death (Mullins 1993, Smith and Krischik 1999).

Imidacloprid is considered to have low to moderate mammalian toxicity (Mullins 1993), largely because it does not bind nerve receptors in mammals sufficiently to trigger nervous activity (Felsot 2001). The selective toxicity of imidacloprid is perhaps best illustrated by its use in flea treatments approved for cats and dogs. Advantage® is applied directly to the animal's skin; this preparation carries very little, if any, risk to the animal or to the people, including children, who may handle the animal (USDA Animal and Plant Health Inspection Service 2002). Chronic (repeated dose) toxicity studies have demonstrated that imidacloprid is not carcinogenic and is not mutagenic and demonstrates no primary reproductive toxicity (Mullins 1993). In studies of metabolic fate in rats, imidacloprid was rapidly absorbed and eliminated in the excreta (90 percent of the dose within 24 hours) with little bioaccumulation (0.5 percent of the dose after 48 hours) and no biologically significant differences occurring between sexes, dose level, and route of administration (USDA Animal and Plant Health Inspection Service 2002). Imidacloprid is an insecticide exhibiting both systemic and contact activity. The spectrum of activity primarily includes sucking insects (aphids, whiteflies, leaf and plant hoppers, thrips, plant bugs, and scales), many Coleopteran species, and selected species of Diptera and Lepidoptera. Activity has also been demonstrated for ants (Hymenoptera); termites (Isoptera); and cockroaches, grasshoppers, and crickets (Orthoptera). No activity has been demonstrated against nematodes or spider mites (Mullins 1993). In spider mites, imidacloprid has been demonstrated to cause an egg-laying enhancement (James and Price 2002). Since spider mites can be a problem in ornamental hemlocks, open-grown imidacloprid-treated trees should be carefully monitored for increases in mite populations.

Little is known about the biotransformation and bioactivity of the metabolites of imidacloprid in hemlock. What is known is that trunk-injected imidacloprid generally requires a week or longer to provide adelgid control, with protection lasting for up to 2 years (Tater et al. 1998, Silcox 2002). The soil injection or soil drench methods of imidacloprid treatments can take several months for translocation to occur but typically has provided better consistency in treatment efficacy and is expected to provide control for at least 3 years. Stem injections should not be used on severely stressed trees.

***Biological control*:** There are no known parasites of adelgids. There are three predatory beetles approved for release and each is unique in its dispersal, reproductive potential, feeding behavior, and suitable climate regimes. They are all very host specific. Where these natural enemies are released is the responsibility of state forest health specialists from each state and the USFS. All of the releases are in infested hemlock stands found primarily along the leading edge of the generally infested area, where hemlocks are still healthy and HWA densities have not yet overwhelmed the trees. The release and establishment of HWA natural enemies is not likely to provide short term control of HWA. It is considered to be a long term approach and will likely require a complex of natural enemies to maintain HWA below damaging levels. It may be years before these predators can self perpetuate sufficiently before any level of success can be determined.

The first predator beetle to be imported and released for biological control is a tiny, black lady beetle, *Sasajiscymnus tsugae*, from Japan. Since 1995, over 1.5 million *S. tsugae* beetles have been released in over 200 sites in 16 eastern states from Georgia to Maine. The recovery of *S. tsugae* beetles in the years following release have been sporadic. The number of beetles recovered have rarely been more than one or two per site. Adult beetles have been captured near some of the release sites more than 6 years after release, and some more than 1/2 a mile from nearest release site.

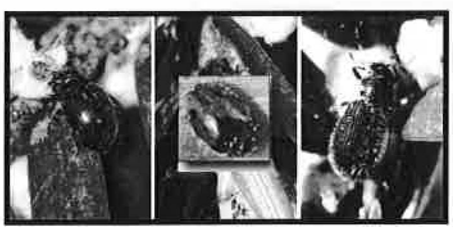


Figure 13. Beetles released for biocontrol (left to right): *Sasjiscymnus tsugae* from Japan, *Scymnus sinuanodulus* from China and *Laricobius nigrinus* from Pacific Northwest.

Another predatory beetle, *Scymnus sinuanodulus*, a lady beetle from China, has been released since 2005. More than 16,000 adult beetles have been released in eight states. So far, few beetles have been recovered from the release sites.

A Derodontid beetle, *Laricobius nigrinus*, from the Pacific Northwest is also approved for release. Mass rearing of this predatory beetle began in 2003, and more than 30,000 beetles have been released in eleven States. Recovery of *L. nigrinus* has been confirmed at most sites. At some release sites, adult beetles are easily found and hundreds of larvae have been recovered.

Release of predator beetles should not take place in close proximity of hemlock trees that have received imidacloprid treatments. Preferred release sites are newly infested sites where trees and adelgids are still healthy. Older infested sites where adelgid densities are

low and recovery of hemlock trees is evident has also proven acceptable. Predator beetles are laboratory reared and the number of predators available in any given year is variable depending in part, on the success of the rearing facilities to locate good quality host material for a food source. Artificial diets are not yet available.

RECOMMENDATIONS

Systemic insecticide treatments using imidacloprid are recommended for HWA control on accessible, individual, high-valued, infested hemlock trees within the park. The continued release and establishment of *Sasajiscymnus tsugae, Scymnus sinuanodulus,* and *Laricobius nigrinus* predatory beetles is also recommended in infested areas of the park on hemlocks that are not in close proximity to chemical treatments.

Where possible, soil treatments are preferred over stem injections as they offer more consistency in treatment efficacy and offer longer protection. Imidacloprid applied at 0.75 grams of a.i. per inch of trunk diameter (dbh) is recommended for the soil injections, and treatment timing should be in the spring or fall. The insecticide recommended for stem injections is IMA-jet® at 5% active ingredient with the number of application sites on the tree determined by dbh. Criteria for number of application sites is as follows: 4 application sites for 6-16 inches dbh, then add one additional application site for each additional 4 inches of dbh. Hemlocks tend to have faster uptake of the stem injected insecticides in the mornings during the spring and fall months when cooler temperatures and higher humidity prevails.

Imidacloprid treated trees should be marked in a manner that will identify the year they were treated, such as a basal spray of color coded paint or tags since theses treatments should provide at least 2-3 years of control and treatments on neighboring trees in subsequent years may be desirable.

With treatment options comes the potential for non-target effects; land managers must balance the risk of these effects with the potential benefits that come with the control of the HWA. As a best management practice, the USFS has previously recommended that hemlocks within 50 feet of open water be treated with a stem injection rather than a soil treatment. Research at the CT Agricultural Research Station has recently demonstrated that imidacloprid binds tightly with organic soils such that movement more than a few centimeters is unlikely when the chemical is placed in the organic layer of the soil. Imidacloprid will leech through mineral soils quite readily so more critical is that applicators use good judgment as to placement of the injector tip in organic soils which in most cases, is less than 3 inches deep. This depth also coincides with the shallow feeder roots of eastern hemlock. With this new research information, soil treatments closer to open water may be acceptable when treatment decisions are based on the soil conditions surrounding each tree to be treated within the 50 foot buffer. In circumstances where rocky porous soils exist or the organic layer in not sufficiently deep enough to handle the injector tip placement, trees should be treated using a stem injection system. Ground

spraying using horticultural oil to protect hemlock seedlings and saplings by means of a backpack sprayer should be considered in areas where protecting younger hemlocks is desirable and where over spray or run off would not contaminate streams, lakes or ponds. One or two applications of a 2% solution of horticultural oil applied in early summer or early fall is recommended as adelgids have not yet developed the wool covering that can impede penetration of the insecticide.

Predatory beetle releases take place in the spring or fall of the year when HWA are actively feeding. The establishment of these natural enemies offers the opportunity for long-term control and may minimize the need for repeated chemical treatments in future years.

Resource managers should annually monitor tree health conditions, adelgid population densities and treatment efficacy. Effective management of HWA requires a vigilant monitoring and treatment program until sufficient biological control agents are established. It is not logistically or economically feasible to chemically treat all trees in numerous or large hemlock stands. Resource managers should continue to prioritize treatment areas and use management strategies involving the selection of individual, accessible, high valued, infested hemlock trees for treatment.

REFERENCES

Akerson, J. and G. Hunt. 1998. HWA status at the Shenandoah National Park. USDA, Forest Service. Hemlock Woolly Adelgid Newsletter # 3: 10-11.

Annand, P.N. 1924. A new species of *Adelges* (Hemiptera: Phylloxeridae). Pan-Pac. Entomol. 1: 79-82.

Avery, M.L., D.G. Decker, D.L. Fisher and T. R. Stafford. 1993. Response of captive blackbirds to the new insecticidal seed treatment. J. Wildl. Manage. 57(3): 652-656.

Bair, M.W. 2002. Eastern Hemlock (*Tsuga Canadensis*) Mortality in Shenandoah National Park. In: Onken, B., R. Reardon, and J. Lashomb (Eds.), Proceedings, Symposium on the hemlock woolly adelgid In Eastern North America, February 5-7, 2002, East Brunswick, NJ. N.J. Agricultural Experiment Station Rutgers. 62-66p.

Baker, W.L. 1972. Eastern forest insects. USDA, Forest Service. Miscellaneous Publication No. 1175. 642 p.

Battles, J.J., N. Cleavitt, T.J. Fahey, and R.A.Evans. 2000. Vegetation composition and structure in two hemlock stands threatened by hemlock woolly adelgid. In: Proceedings of a Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America, edited by K.A. McManus, K.S. Shields, and D.R. Souto. Pp.55-61.

Bentz, S.E., L.G.H. Riedel, M.R. Pooler, and A. Townsend. 2002. Hybridization and self-compatibility in controlled pollinations of eastern north American and asian hemlock (*Tsuga*) species. Journal of Arboriculture 28(4): 200-205.

Butin, E., M. Montgomery, N. Havill, and J. Elkinton. 2002. Pre-release host range assessment for classical biological controls: Experience with predators for the hemlock woolly adelgid. In: Onken, B., R. Reardon, and J. Lashomb (Eds.), Proceedings, Symposium on the hemlock woolly adelgid In Eastern North America, February 5-7, 2002, East Brunswick, NJ. N.J. Agricultural Experiment Station Rutgers. 205-213 p.

Chaney, W.R. 1986. Anatomy and physiology related to chemical movement in trees. Journal of Arboriculture 12(4): 85-91.

Cheah, C.C. 1998. Establishing *Pseudoscymnus tsugae* (Coleoptera: Coccinellidae) as a biological control agent for hemlock woolly adelgid. Environmental Assessment prepared by the Connecticut Agricultural Experiment Station. Unpub. Report. 6 p.

Cheah, C. A. S.-J. and M.S. McClure. 2000. Seasonal synchrony of life cycles between the exotic predator, Pseudoscymnus tsugae (Coleoptera: Coccinellidae) and its prey,

the hemlock woolly adelgid Adelges tsugae (Homoptera: Adelgidae). Agric. and For. Entom. 2:241-251.

Costa, S. and B. Onken. 2006. Standardized Sampling for Detection and Monitoring of Hemlock Woolly Adelgid in Eastern Hemlock Forests. FHTET-2006-16. U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team; 11p.

Danoff-Burg, J.A. and Simon Bird. 2002. Hemlock Woolly Adelgid and Elongate Hemlock Scale: Partners in Crime. In: Onken, B., R. Reardon, and J. Lashomb (Eds.), Proceedings, Symposium on the hemlock woolly adelgid In Eastern North America, February 5-7, 2002, East Brunswick, NJ. N.J. Agricultural Experiment Station Rutgers. 254-268 p.

Doccola, J.J. P.M. Wild, I. Ramasamy, P. Castillo, and C. Taylor. 2003. Efficacy of arborjet viper microinjections in the management of hemlock woolly adelgid. Journal of Arboriculture. 29(6): 327-330.

Drooz, A.T. 1989. Insects of eastern forests. USDA, Forest Service. Micellaneous Publication No. 1426. 608 p.

Eschtruth, Anne K., N.L. Cleavitt, J.J. Battles, R.A. Evans, and T.J. Fahey. 2006. Vegetation dynamics in declining eastern hemlock stands: nine years of forest response to hemlock woolly adelgid infestations. Canadian Journal of Forest Research. *In press*.

Evans, R.A. 2000. Draft Environmental Assessment: for the Release and Establishment of *Pseudoscymnus tsugae* (Coleoptera: Coccinellidae) as a Biological Control Agent for Hemlock Woolly Adelgid (*Adelges tsugae*) at the Delaware Water Gap National Recreation Area. USDI, National Park Service, Northeastern Region. 23 p.

Evans, R.A. 2002. Hemlock Ecosystems and Hemlock Woolly Adelgid at Delaware Water Gap National Recreation Area (yearly report). USDI, National Park Service, Northeastern Region. 6p.

Evans, R.A. 2003. Hemlock Ecosystems and Hemlock Woolly Adelgid at Delaware Water Gap National Recreation Area (yearly report). USDI, National Park Service, Northeastern Region. 20p.

Evans, R.A. 2006. Hemlock Ecosystems and Hemlock Woolly Adelgid at Delaware Water Gap National Recreation Area (yearly report). USDI, National Park Service, Northeastern Region. 11p.

Felsot, A. 2001. Admiring Risk Reduction: Does Imidacloprid have what it takes? Agrichemical and Environmental News 186: 2-13.

Godman, R.M. and K. Lancaster. 1990. *Tsuga canadensis* (l.) Carr., eastern hemlock. In: R.M. Burns and B.H. Honkala, eds. Silvics of North America, vol.1, conifers. USDA Forest Service, Agriculture Handbook No. 654. pp. 604-612.

Helms, J.A., ed. 1998. The dictionary of forestry. The Society of American Foresters. Bethesda, MD.

Hennessey, R.D. and M.S. McClure. 1995. Field release of a non-indigenous lady beetle, *Pseudoscymnus* sp. (Coleoptera: Coccinellidae), for biological control of hemlock woolly adelgid, *Adelges tsugae* (Homoptera: Adelgidae). Environmental Assessment prepared by USDA, Animal and Plant Health Inspection Service, Riverdale, MD. Unpub. Report. 6 p.

Hepting, G.H. 1971. Diseases of forest and shade trees of the United States. USDA Forest Service, Agricultural Handbook 386. 488-491.

James, D.G. and T.S. Price. 2002. Imidacloprid boosts TSSM egg production. Agrichemical and Environmental News 189: 1-11.

Jenkins, J.C., J.D. Aber, and C.D. Canham. 1999. Hemlock woolly adelgid impacts on community structure and N cycling rates in eastern hemlock forests. *Canadian Journal of Forest Research* 29: 630-645.

Johnson, W.T. and H.H. Lyon. 1988. Insects that Feed On Trees and Shrubs. 2nd Ed. Cornell University Press, Ithaca, N.Y. 102-105 p.

Lapin, B. 1994. The Impact of Hemlock Woolly Adelgid on Resource in the Lower Connecticut Valley. USDA. Northeastern Center for Forest Health research, Hamden, CT. 45p.

Mayer, M., R. Chianese, T. Scudder, J. White, K. Vongpaseuth, and R. Ward. 2002. Thirteen Years of Monitoring the Hemlock Woolly Adelgid In New jersey Forests. In: Onken, B., R. Reardon, and J. Lashomb (Eds.), Proceedings, Symposium on the hemlock woolly adelgid In Eastern North America, February 5-7, 2002, East Brunswick, NJ. N.J. Agricultural Experiment Station Rutgers. 50-60 p.

McAvoy, T., W. Mays, S.M. Salom and L.T. Kok. 2002. Preliminary report of the impact of Merit (Imidacloprid) on hemlock woolly adelgid (Adelges tsugae) and non-target species. Department of Entomology, Virginia Polytech Institute and State University, Blacksburg, VA. Unpub. Report. 14 p.

McClure, M.S. 1989. Evidence of a polymorphic life cycle in the hemlock woolly adelgid, *Adelges tsugae* (Homoptera: Adelgidae). Ann. Entom. Soc. Am. 82:50-54.

McClure, M.S. 1992a. Effects of implanted and injected pesticide and fertilizers on the survival of Adelges tsugae (Homoptera: Adelgidae) and on the growth of Tsuga canadensis. Journal Econ. Entomol. 85(2) 468-472.

McClure, M.S. 1992b. Hemlock woolly adelgid. American Nurseryman 175(6): 82-89.

McClure, M.S. 1995. Managing hemlock woolly adelgid in ornamental landscapes. Bulletin 925. Connecticut Agricultural Experiment Station. 7 p.

McClure, M.S. 1996. Biology of *Adelges tsugae* and its potential for spread in the Northeastern United States. In: Salom, S.M., T.C. Tigner, and R.C. Reardon, (Eds.), Proceedings, First hemlock woolly adelgid review, 12 October, 1995, Charlottesville, VA. USDA, Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV, FHTET-96-10: 16-25.

McClure, M.S. 2001. Biological control of hemlock woolly adelgid in the Eastern United States. USDA, Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV, FHTET-2000-08. 10 p.

McClure, M.S. 2002a. The Elongate Hemlock Scale, *Fiorinia externa* Ferris (Homoptera: Diaspididae): A New Look at an Old Nemesis. In: Onken, B., R. Reardon, and J. Lashomb (Eds.), Proceedings, Symposium on the hemlock woolly adelgid In Eastern North America, February 5-7, 2002, East Brunswick, NJ. N.J. Agricultural Experiment Station Rutgers. 248-253 p.

McClure, M.S. 2002b. Pest Alert: Elongate Hemlock Scale. USDA, Forest Service, Northeastern Area, Morgantown, WV, NA-PR-01-02. 2p.

McClure, M.S. and C.A.S-J. Cheah. 1998. Released Japanese ladybugs are multiplying and killing hemlock woolly adelgids. Frontiers of Plant Science. 50(2): 6-8 p.

McClure, M.S. and C.A.S-J. Cheah. 2002. Establishing Pseudoscymnus tsugae Sasaji and McClure (Coleoptera:Coccinellidae) for the biological control of the hemlock woolly adelgid, Adelges tsugae, Annand (Homoptera:Adelgidae), in the Eastern United States. In: Onken, B., R. Reardon, and J. Lashomb (Eds.), Proceedings, Symposium on the hemlock woolly adelgid In Eastern North America, February 5-7, 2002, East Brunswick, NJ. N.J. Agricultural Experiment Station Rutgers. 351-352 p.

McClure, M.S., S.M. Salom, and K.S. Shields. 2001. Hemlock woolly adelgid. USDA, Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV, FHTET-2001-03. 14 p.

Millington, W. 1989. Hemlock woolly adelgid infestations discovered. Fall Newsletter of the Research and Resource Planning Division of Delaware Water Gap National Recreation Area.

Montgomery, M.E. 1999. Woolly adelgids in the southern Appalachians: Why they are harmful and prospects for control. In: Gibson, P. and C. Parker, (Eds.), Proceedings of the Appalachian biological control initiative workshop. USDA, Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV, FHTET-98-14. 59 p.

Montgomery, M.E. and S.M. Lyons. 1996. Natural enemies of adelgids in North America: Their prospect for biological control of *Adelges tsugae* (Homoptera: Adelgidae). In: Salom, S.M., T.C. Tigner, and R.C. Reardon, (Eds.), Proceedings, First hemlock woolly adelgid review, 12 October, 1995, Charlottesville, VA. USDA, Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV, FHTET-96-10: 89-102.

Mullins, J.W. 1993. Imidacloprid: a new nitroguanidien insecticide. In: Duke, S.O., J.J. Menn, and J.R. Plimmer (eds.), Pest control with enhanced environmental safety. American Chemical Society Symposium, ASC, Washington DC: 183-189.

Myers, W.L. and R.R. Irish. 1981. Vegetation survey of Delaware Water Gap National Recreation Area. Final Report, USDAI National Park Service.

NCDC. 2006. National Climatic Data Center. Monthly Palmer drought indices for Pike County, Pennsylvania from 1990 – 2005. http://www.ncdc.noaa.gov/oa/ncdc.html [cited March 15, 2006].

Onken, B., D. Souto, and R. Rhea. 1999. Environmental Assessment for the release and establishment of *Pseudosymnus tsugae* (Coleoptera: Coccinellidae) as a biological control agent for the hemlock woolly adelgid. USDA, Forest Service, Morgantown, WV.

Onken, B. and D. Souto. 2006. Hemlock Woolly Adelgid Newsletter, Issue No. 7. USDA, Forest Service, Forest Health Protection.

Quimby, J. 1996. Value and importance of hemlock ecosystems in the eastern United States. In: S>M> Salom, T.C. Tigner, and R.C. Reardon, eds. Proceedings of the First Hemlock Woolly Adelgid Review, Charlottsville, VA, 1995. USDA Forest Service, Forest Health Technology Enterprise Team-Morgantown, WV. FHTET 96-10. pp1-8.

Rhea, J.R. 1996. Preliminary results for the chemical control of hemlock woolly adelgid in ornamental and natural settings. In: Salom, S.M., T.C. Tigner, and R.C. Reardon, (Eds.), Proceedings, First hemlock woolly adelgid review, 12 October, 1995, Charlottesville, VA. USDA, Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV, FHTET-96-10: 89-102.

Ross, R.M., L.A. Redell, and R. Bennett. 2004. Mesohabitat Use of Threatened Hemlock Forests by Breeding Birds of the Delaware River Basin in Northeastern United States. Natural Areas Journal, 24:307-315.

Sasaji, H. and M.S. McClure. 1997. Description and distribution of Pseudoscymnus tsugae sp. Nov. (Coleoptera: Coccinellidae), an important predator of hemlock woolly adelgid in Japan. Annals of the Ent. Soc. Am., 90:563-578.

Schroeder, M.E. and R.F. Flattum. 1984. The mode of action and neurotoxic properties of the nitromethylene heterocycle insecticides. Pestic. Biochem. Physiol. 22: 148-160.

Schweitzer,D.1994. Hemlock woolly adelgid and native hemlock lepidoptera. Memorandum to state Natural Heritage Programs and stewardship staff at The Nature Conservancy offices in the ERO states, and NC, SC, GA, and Great Smokey Mountains National Park. (May 19).

Sciascia, J.C. and Ellen Pehek. 1995. Small mammal and amphibian populations and their microhabitat preferences within selected hemlock ecosystems in the Delaware Water Gap National Recreation Area. Draft final report, 39pp.

Silcox, C.A. 2002. Using imidacloprid to control hemlock woolly adelgid in the Eastern United States. In: Onken, B., R. Reardon, and J. Lashomb (eds.), Proceedings, Symposium on the hemlock woolly adelgid In Eastern North America, February 5-7, 2002, East Brunswick, NJ. N.J. Agricultural Experiment Station Rutgers. 280-287 p.

Smith, S.F. and V.A. Krischik. 1999. Effects of systemic imidacloprid on *Coleomegilla maculate* (Coleoptera: Coccinellidae). Envir. Entomol. 28(6): 1189-1195.

Snyder, C., J. Young, D. Smith, D. Lemarie, R. Ross, and R. Bennett. 1998. Influences of eastern hemlock decline on aquatic biodiversity of Delaware Water Gap National Recreation Area. Final Report to the National Park Service.

Tattar, T.A., J.A. Dotson, M.S. Ruizzo, and V.B. Bruce. 1998. Translocation of imidacloprid in three tree species when trunk and soil injected. Journal of Arboriculture 24: 54-56.

Tattar, T.A. and S.J. Tattar. 1999. Evidence of the downward movement of materials injected into trees. Journal of Arboriculture 25(6): 325-332.

USDA Animal and Plant Health Inspection Service. 2002. Draft. Use of Imidacloprid formulations for the control and eradication of wood boring pests: Assessment of the potential for human health and environmental impacts.

Van Driesche, R.G. S. Healy and R.C. Reardon. 1996. Biological Control of Arthropod Pests of the Northeastern and North Central Forest in the United States: A Review

and Recommendations. USDA, Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV, FHTET-96-19: 10.

Steward, V.B. and T.A. Horner. 1994. Control of hemlock woolly adelgid using soil injection of systemic insecticides. J. of Arbriculture 20(5):287-288.

Wallace, M.S. and F.P. Hain. 1998. The effects of predators of the hemlock woolly adelgid in north Carolina and Virginia. USDA, Forest Service. Hemlock Woolly Adelgid Newsletter # 3: 3.

Webb, R.E., J.R. Frank, and M. J. Raupp. 2003. Eastern hemlock recovery form hemlock woolly adelgid damage following Imidacloprid therapy. Journal of Arboriculture. 29(5): 298-302.

Yamasaki, M., R.M. DeGraaf, and J.W. Lanier. 2000. Wildlife habitat associations in eastern hemlock – birds, smaller mammals, and forest carnivores. In: Proceedings of a Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America, edited by K.A. McManus, K.S.Shields, and S.R.Souto. pp.135-141.

Young, J.A., D.R. Smith, C.D. Snyder, and D. P. Lemarie. 1998. A landscape-based sampling design to assess biodiversity losses from eastern hemlock decline.